Technical Note DOER-E6
March 1999

Estimating Dredging Sediment Resuspension Sources

PURPOSE: The technical note herein presents an approach for estimating the suspended-sediment source from cutterhead, hopper, and clamshell dredges. The approach involves modification of an existing method developed from limited field data. These estimates are needed to provide input to a numerical model called SSFATE (Suspended Sediment FATE) that is being developed under the Dredging Operations and Environmental Research (DOER) Program.

BACKGROUND: A need exists for numerical modeling tools to address questions related to environmental windows associated with dredging projects. One such question relates to where and in what quantity suspended sediment from dredging operations moves away from the dredging location. With this information, decision makers would be aided in determining reasonable start and end dates for environmental windows related to fish migratory pathways, sedimentation on sensitive benthic habitats, and other environmental issues. The SSFATE model is being developed under DOER to provide field offices with such a tool. The basic computations are based on a particle-tracking approach with each particle representing a certain amount of sediment mass that is generated at the location of the dredging operation. These particles are then diffused and transported throughout the water body of interest while undergoing settling. Suspended-sediment concentrations at any location at any time in the simulation can be determined from the number of particles occupying some volume surrounding the point of interest.

SSFATE will be a versatile model containing many features; for instance, ambient currents can either be imported from a numerical hydrodynamic model or "painted" using limited field data, and results can be animated over GIS layers depicting sensitive environmental areas. However, regardless of the sophistication and versatility of SSFATE, an integral part of the model will be the estimation of the amount of sediment at the dredging site that is released to the water column, i.e., the sediment-source strength and its vertical distribution. A review of existing literature on field measurements of suspended-sediment concentrations near dredges and proposed approaches for generating sediment sources resulted in the proposed simplified approach discussed in this technical note.

FACTORS INFLUENCING SOURCE STRENGTH: Generally, the major factors influencing the strength of the sediment source at a dredge are the sediment type being dredged, the type of dredge and the manner in which the dredge is operated, and ambient currents. If the sediment is primarily sand, material may be released to the water column, but it quickly settles out. However, if the material is primarily fine grained, it can remain in suspension for an extended time while being subjected to the processes of diffusion, settling, and transport. Different types of dredges typically release different percentages of the dredged volume of sediments into the water column. For example, clamshell dredges release a higher percentage of the dredged volume than generally occurs for a cutterhead dredge. Obviously, the size and manner in which a particular dredge is operated also influence the amount of sediment release. For example, for a hydraulic cutterhead

dredge, sediment release increases with higher speed of cutterhead rotation, higher swing speed, and larger cutterhead diameter.

EXISTING APPROACHES FOR ESTIMATING SOURCE STRENGTHS: Two existing approaches for estimating the sediment mass released by a dredge can be found in the literature. The first is based on Nakai's (1978) concept of a turbidity generation unit (TGU), which varies with sediment type and dredge type (Table 1) and has the units of kilograms/cubic meter of dredged sediment. The parameter d in Table 1 is the sediment-particle diameter. Pennekamp et al. (1996) list a similar parameter for various types of dredges (Table 2). However, no indication of the sediment type is provided. The basic equation proposed by Nakai (1978) to compute the rate of sediment mass released by a given dredging operation is

Table 1
Turbidity Generation Unit Values from Nakai (1978)

Type of Dredge	Power or Bucket Volume	Dredged Materials: $d < 0.74$ mm %	Dredged Materials: $d < 0.005$ mm %	Dredged Materials: Classification	TGU kg/cu m
Hydraulic cutterhead	4,000 hp	99.0	40.0	Silty clay	5.3
	4,000 hp	98.5	36.0	Silty clay	22.5
	4,000 hp	99.0	47.5	Clay	36.4
	4,000 hp	31.8	11.4	Sandy loam	1.4
	4,000 hp	69.2	35.4	Clay	45.2
	4,000 hp	74.5	50.5	Sandy loam	12.1
	2,500 hp	94.4	34.5	Silty clay	9.9
	2,000 hp	3.0	3.0	Sand	0.2
	2,000 hp	2.5	1.5	Sand	0.3
	2,000 hp	8.0	2.0	Sand	0.1
Hopper	Two at 2,400 hp each	92.0	20.7	Silty clay loam	7.1
	1,800 hp	83.2	33.4	Silt	25.2
Mechanical grab	8 cu m	58.0	34.6	Silty clay	89.0
	4 cu m	54.8	41.2	Clay	84.2
	3 cu m	45.0	3.5	Silty loam	15.8
	3 cu m	62.0	5.5	Silty loam	11.9
	3 cu m	87.5	6.0	Silty loam	17.1
Mechanical bucket		10.2	1.5	Sand	17.6
		12.7	12.5	Sandy loam	55.8

$$M = (V)(\mathrm{TGU}) / (R74/Ro) \qquad (1)$$

where

TGU = turbidity generation unit, kg/cu m

M = mass rate of released sediment, kg/sec

V = volume rate of dredging, cu m/sec

Ro = fraction of dredged sediment that has a critical resuspension velocity smaller than the ambient current velocity

*R*74 = fraction of dredged sediment that has a diameter less than 0.074 mm

Table 2
Turbidity Generation Unit Values from Pennekamp et al. (1996)

Dredge Type	Production cu m/hr	Vertically Averaged Concentration Above Background, mg/ℓ	TGU kg/cu m
Hopper	5,500	400	14
	5,400	150	3
	1,750	15	1-5
	2,170	60	8-22
Open clamshell	90	35	3
Tight clamshell	166	100	19
Open bucket	714	110	18-21

Given the ambient current and the grain-size analysis of the dredged material, *R*74 can be determined from the grain-size analysis and *Ro* can be determined using typical values for critical resuspension velocity such as those given by Nakai (1978) in Table 3. With the production rate known and a value of TGU selected, the rate of sediment release can then be determined from Equation 1.

Table 3
Critical Resuspension Velocity

Soil Type	Particle Size, mm	Critical Resuspension Velocity, cm/sec
Clay	0.005	0.03
Silt	0.005-0.074	0.03-7.0
Fine sand	0.074-0.42	7.0-15.0
Rough sand	0.42-2.0	15.0-35.0

The second method is described by Averett and Hayes (1995) as the Correlation Method. This method consists of empirical models that have been developed based on observed resuspension rates, sediment characteristics, and dredge-operating parameters at a series of field sites (Vann 1983; Hayes 1987; Hayes, McLellan, and Truitt 1988; McLellan et al. 1989). At the present time, empirical models have been developed only for cutterhead and open-bucket dredges (Collins 1995; Kuo and Hayes 1991).

LIMITATIONS: Both methods are based on limited field data. Because of the highly variable nature of dredging operations, neither of the existing methods for estimating the strength of sediment sources yields highly accurate predictions. Collins (1995) presents a comparison of predicted and observed concentrations using an empirical model for a cutterhead dredge that is based on data

collected in Calumet Harbor, Illinois (Figure 1). The two data sets labeled Savannah River are for partial cuts (P.C.) and buried cuts (B.C.) of the cutterhead. The results shown in Figure 1 illustrate that when the correlation method (empirical model) is applied to a dredging activity different from the one where field data were collected and used to determine model coefficients, the results can differ by 1-2 orders of magnitude. Thus, at this time, implementation into SSFATE of the more sophisticated empirical models over the use of the TGU method would not appear to result in better predictions of sediment sources.

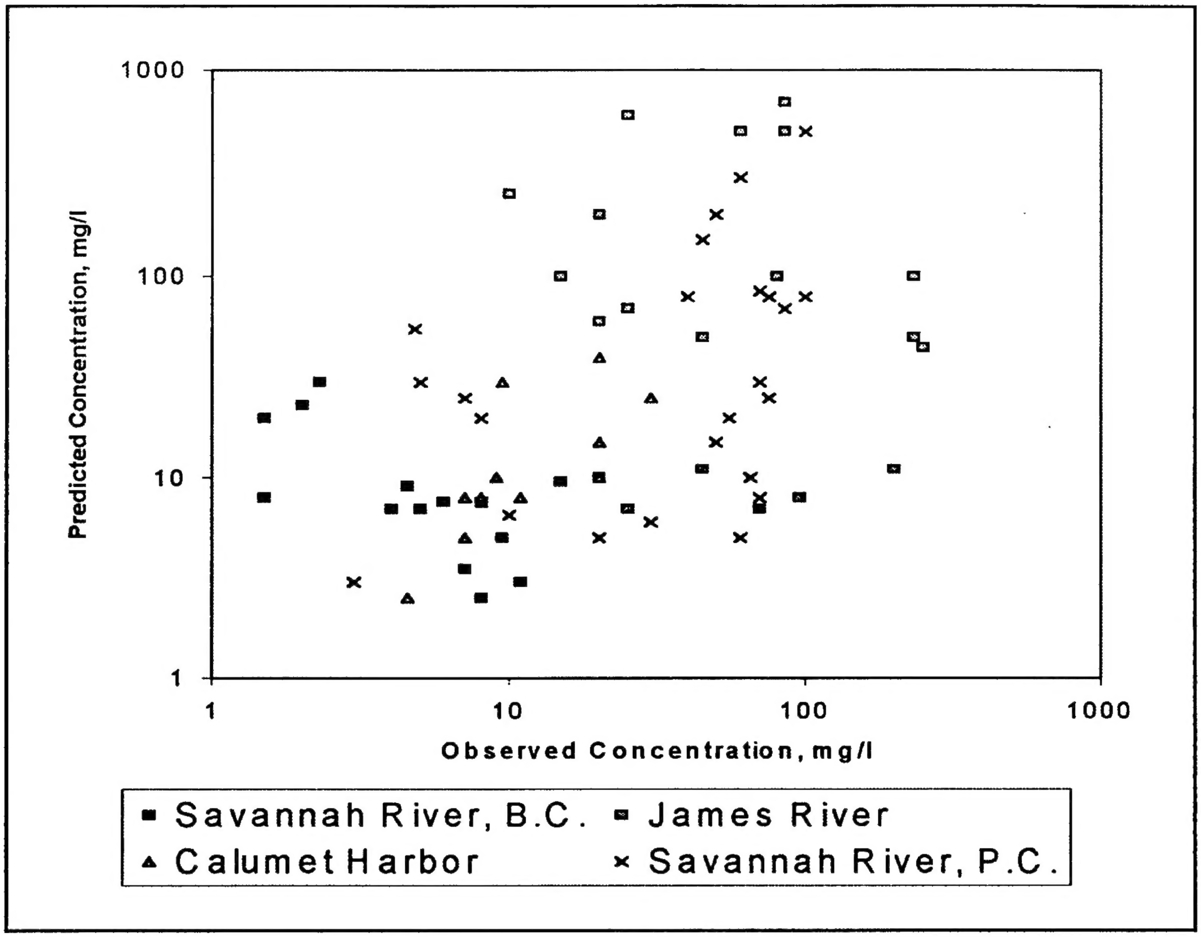

Figure 1. Sediment resuspension predictions for cutterhead dredges (from Collins 1995)

Although predictions using the TGU method must also be viewed with caution, it is the simpler of the two existing approaches. The data required are the dredge type, the grain-size analysis of bed material, the ambient current velocity, and the production rate of the dredge. Of course, the timing of the dredging operation, e.g., the time required for a hopper dredge to carry the dredged material to a disposal site and return to the dredging site, must also be known. The following use of the TGU method is proposed for implementation in SSFATE.

MODIFIED USE OF THE TGU METHOD: As previously noted, the type of dredged material, the type of dredge, and the operation of the dredge, e.g., taking a full cut versus a partial cut with a cutterhead dredge, are major factors influencing the appropriate value of the TGU for

use in Equation 1. Much variability is in these factors for a particular dredging operation and thus in the value of the TGU to be selected. An inspection of Tables 1 and 2 reveals that the maximum values of the TGU for cutterhead, hopper, and clamshell dredges are about 45, 25, and 90 kg/cu m, respectively. The basic problem is how to determine a TGU value for a particular dredging operation involving one of these three dredges. In the proposed approach, such a value is determined by first selecting a typical suspended sediment concentration likely to be produced by the dredging operation.

Figures 2 and 3, which show a range of measured suspended-sediment concentrations near cutterhead and hopper dredges for different soil types, have been constructed from available field data. A good review of these data is provided by Herbich and Brahme (1991). Obviously the operating and ambient conditions under which these data were collected are highly variable. However, one should take into consideration the following general guidelines:

a. For a hydraulic cutterhead dredge, sediment resuspension increases with higher speed of rotation, higher swing speed, larger cutter diameter, and greater depth of cut.

b. For a trailing hydraulic hopper dredge, sediment resuspension increases with increased hopper filling speed and travel speed of dredge.

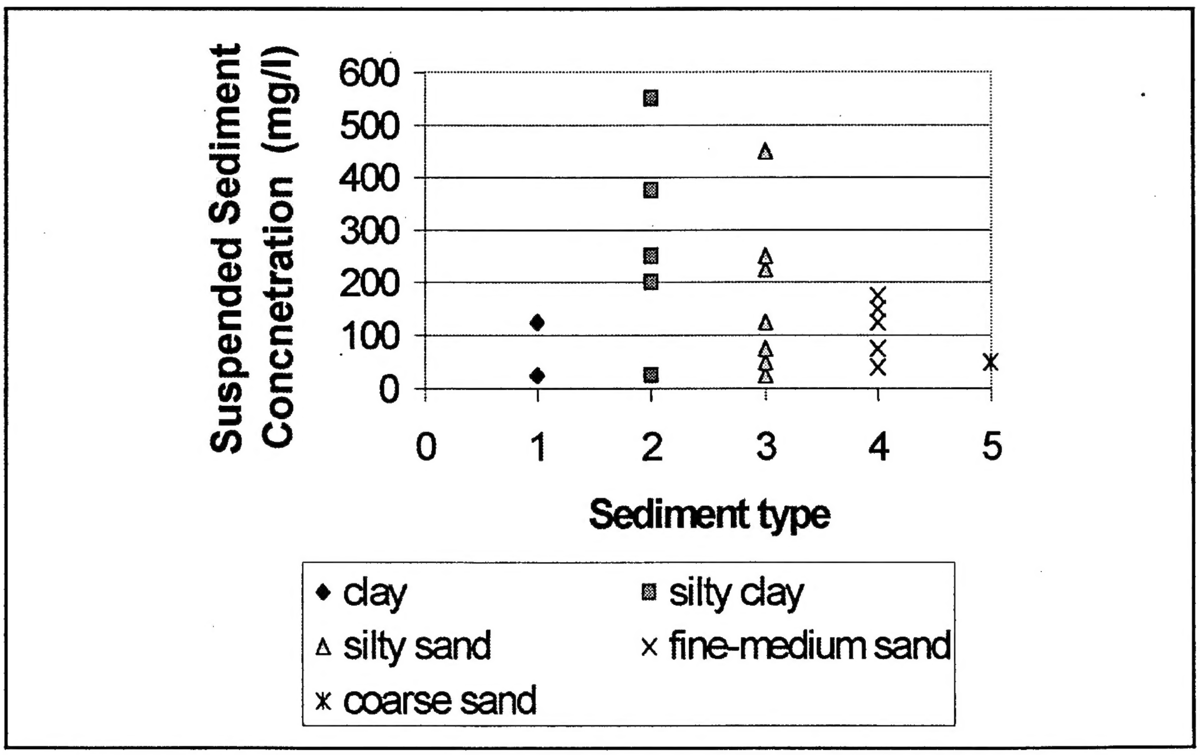

Figure 2. Observed resuspended-sediment concentrations versus soil type for a cutterhead dredge

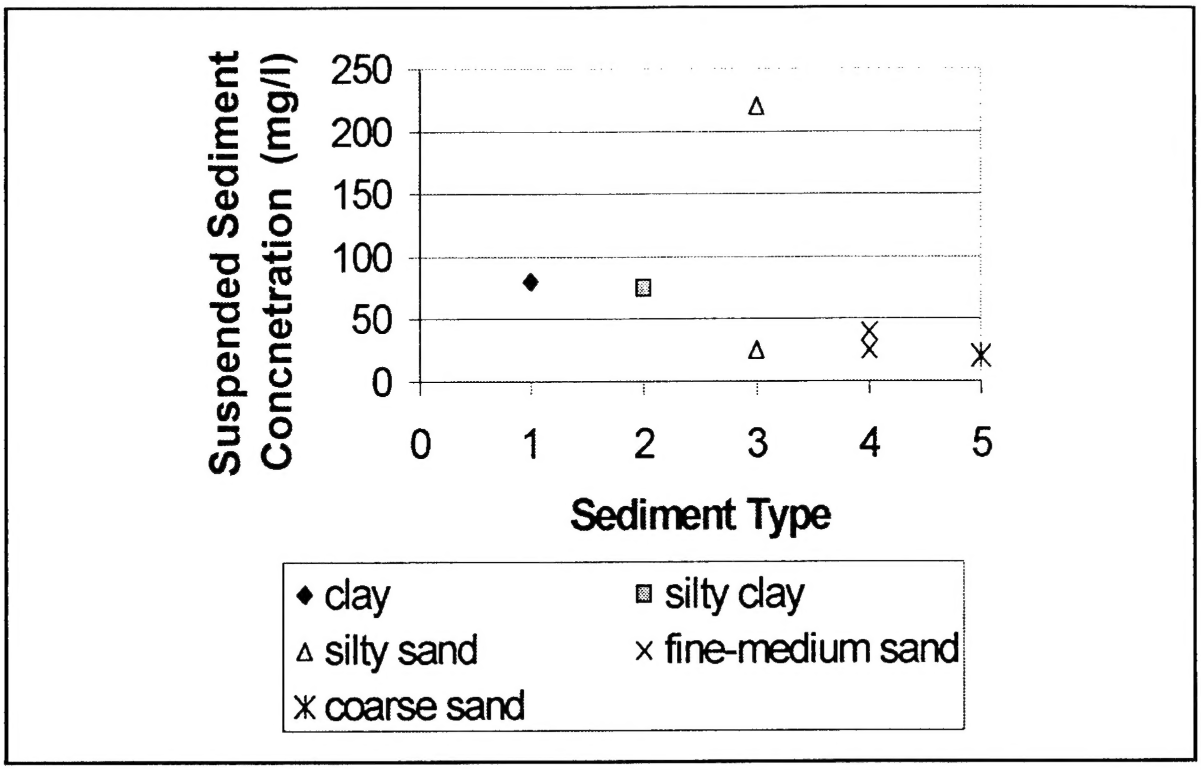

Figure 3. Observed resuspended-sediment concentrations versus soil type for a hopper dredge with no overflow

A typical concentration value can be selected from Figures 2 and 3 for the most predominant (greater than 70 percent) type of sediment being dredged from clay, silty clay (mixtures), silty sand (mixtures), fine-medium sand, and coarse sand.

Figures 2 and 3 are for cutterhead and hopper dredges, respectively. Clamshell dredging operations are slow, and the output rate is low compared with cutterhead and hopper dredges. In view of the limited use of clamshell dredges, few field data are available on the amount of sediment resuspension related to the type of sediment being dredged. However, general guidelines can be proposed. For example, clamshell dredges usually generate high turbidity while dredging fine sediments and stiff clays (McLellan et al. 1989). This turbidity can be distributed throughout the water column because of the action of raising the bucket from the bottom up through the water surface with subsequent disposal in a barge or scow. Based upon the limited data (Herbich and Brahme 1991) available, near-bed sediment concentrations may vary from 200-800 mg/ℓ. The following should be taken into consideration when selecting a value between those two bounds:

a. Loose clay layers will result in higher concentrations, whereas, stiff clays with high density will result in lower suspensions.

b. Greater impact of the bucket on the bottom results in higher sediment release to the water column.

c. Closed buckets generally result in lower suspended-sediment concentrations than those generated with open buckets.

After an appropriate concentration has been selected for the particular sediment type and dredge type, it is proposed that a corresponding value for the TGU be determined from a linear interpolation between a value of zero for no sediment release (zero concentration) and the maximum values shown for either a cutterhead (max TGU = 45 kg/cu m corresponding to max concentration of about 600 mg/ℓ), hopper (max TGU = 25 kg/cu m corresponding to max concentration of about 200 mg/ℓ), or clamshell (max TGU = 90 kg/cu m corresponding to max concentration of about 800 mg/ℓ) dredge. The assumption of a linear variation of the TGU with suspended-sediment concentration seems to be reasonable for concentrations occurring very near the dredge, but no data exist for confirmation. Maybe the variation of the TGU with suspended-sediment concentration has a different functional form, e.g., exponential. However, assuming a linear variation over an exponential variation gives the most conservative value, which is more desirable when predicting suspended-sediment concentrations for use in addressing environmental concerns. Assuming the dredging production rate is known (after the determination of the TGU, *Ro*, and *R*74 values), the rate of sediment mass released can be determined from Equation 1.

Another important part of the sediment source strength term for input to SSFATE is the vertical distribution of the sediment mass computed from Equation 1. Most field data collected near dredging operations are at locations some distance away from the dredge. Therefore, based upon data such as these, accurately assigning vertical distributions at the dredge where the sediment is released is difficult. For preliminary implementation in SSFATE, the sediment resuspended near the bottom by the cutterhead dredge and the hopper dredge is assumed to be released over the bottom 2.5 and 1.5 m of the water column, respectively. The vertical distributions shown in Figures 4 and 5 are assumed.

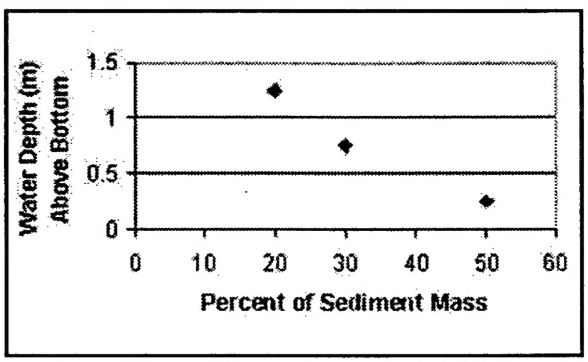

Figure 4. Assumed vertical distribution of bottom sediment source for a hopper dredge

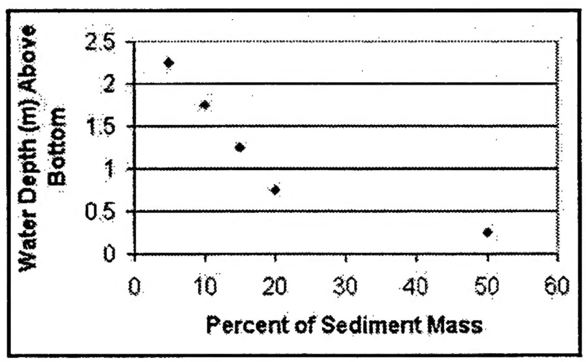

Figure 5. Assumed vertical distribution of bottom sediment source for a cutterhead dredge

Sediment released from a clamshell dredge will occur throughout the entire water column as the bucket is raised to the surface. Thus, the vertical distribution shown in Figure 6 is assumed for implementation in SSFATE. It should be stressed that although these distributions seem reasonable, field data are needed to verify the accuracy of the assumed distributions.

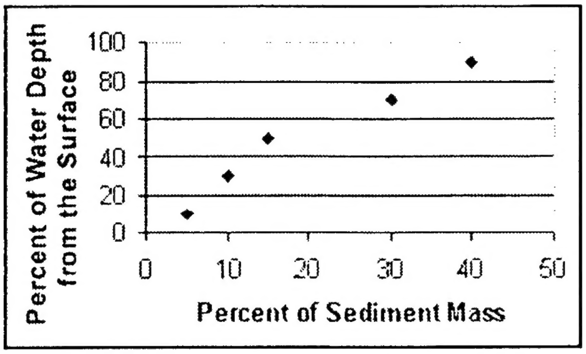

Figure 6. Assumed vertical distribution for sediment source for a clamshell dredge

All of the discussion above has focused on sediment sources that are associated with the removal of material from the bottom. However, when hopper or clamshell dredges operate with overflow from the hoppers or barges, sediment is released at or near the water surface. Typically, overflow dredging only occurs when the sediment being dredged is primarily sandy material. This allows for a higher accumulation of coarse-grained material in the hoppers with the small fine-grained fractions of silt and clay overflowing from the hopper bins into the surface water. Bartos (1977) reported that suspended-sediment concentrations in the upper water column resulting from an overflow operation in San Francisco Bay were several hundred milligrams/liter. The dredged sediment was inorganic clay, and 58 percent had a diameter less than 0.074 mm. Pennekamp et al. (1996) reported a vertically averaged suspended-sediment concentration of about 400 mg/ℓ for a hopper dredge operating with overflow at Rotterdam in The Netherlands. As a conservative estimate for implementation of a near-surface sediment source term for hopper overflow in SSFATE, the sediment mass rate released because of overflow will be computed to be the fraction of fine-grained material in the sediment being dredged times the production rate of the hopper dredge. It will be assumed that the sediment mass released will be uniformly distributed over the upper 2 m of the water column along the horizontal length of the overflow. If the overflow is collected and released below the water surface, the vertical location of the release will be the location of the sediment source in SSFATE.

CONCLUSIONS: An approach for estimating the strength and vertical distribution of sediment sources generated by cutterhead, hopper, and clamshell dredges has been proposed for inclusion in the SSFATE model being developed under DOER. It is believed that based upon available field data, the approach is reasonable and should provide conservative estimates of the amount of sediment released into the water column during dredging activities. As additional field data become available, assumptions such as the linear variation of the TGU with suspended-sediment concentrations and the vertical distributions for the released sediment may need to be modified.

ACKNOWLEDGMENTS: Permission was granted by the Headquarters, U.S. Army Corps of Engineers to publish this information.

POINTS OF CONTACT: For additional information, contact one of the authors, Drs. Billy H. Johnson (601-634-3425, *johnsob1@mail.wes.army.mil*) or Nana Pachure (601-634-3213, *parchut@mail.wes.army.mil*), or the program managers of the Dredging Operations Environmental Research Program, Mr. E. Clark McNair (601-634-2070, *mcnairc@mail.wes.army.mil*) and Dr. Robert M. Engler (601-634-3624, *englerr@mail.wes.army.mil*). This technical note should be cited as follows:

Johnson, B. H., and Pachure, T. M. (1999). "Estimating dredging sediment resuspension sources," *DOER Technical Notes Collection* (TN DOER-E6). U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer*

REFERENCES

Averett, D. E., and Hayes, D. F. (1997). "Estimating contaminant losses during dredging." *Proceedings of the seventeenth United States-Japan experts meeting on management of bottom sediments containing toxic substances.*

Bartos, M. J. (1977). "Classification and engineering properties of dredged material," Technical Report D-77-18, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Collins, M. A. (1995). "Dredging-induced near field resuspended sediment concentrations and source strengths," Miscellaneous Paper D-95-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hayes, D. F. (1987). "Removal of contaminated aquatic sediments using a cutterhead dredge," Unpublished paper, Department of Civil Engineering, Colorado State University, Fort Collins, CO.

Hayes, D., McLellan, T., and Truitt, C. (1988). "Demonstrations of innovative and conventional dredging equipment at Calumet Harbor, Illinois," Miscellaneous Paper EL-88-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Herbich, J. B., and Brahme, S. B. (1991). "Literature review and technical evaluation of sediment resuspension during dredging," Contract Report HL-91-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Kuo, A. Y., and Hayes, D. F. (1991). "A model for turbidity plume induced by bucket dredge," *ASCE Journal of Waterways, Port, Coastal, and Ocean Engineering*, American Society of Civil Engineers, November.

McLellan, T. N., Havis, R. N., Hays, D. F., and Raymond, G. L. (1989). "Field studies of sediment resuspension characteristics of selected dredges," Technical Report HL-89-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Nakai, O. (1978). "Turbidity generated by dredging projects, management of bottom sediments containing toxic substances." *Proceedings of the third United States-Japan experts meeting*, EPA-600/3-78-084, 1-47.

Pennekamp, J. G. S., Epskamp, R. J. C., Rosenbrand, W. F., Mullie, A., Wessel, G. L., Arts, T., and Deibel, I. K. (1996). "Turbidity caused by dredging; viewed in perspective," *Terra et Aqua* 64, 10-17.

Vann, R. G. (1983). "James River, Virginia, dredging demonstration in contaminated material (kepone), dustpan versus cutterhead," Report, U.S. Army Engineer District, Norfolk, Norfolk, VA.